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Free vibration of laminated composite stiffened saddle shell roofs with cutouts

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ABSTRACT : *In this paper, the finite element method has been applied to solve free vibration problems of laminated composite stiffened saddle shells with cutouts employing the eight-noded curved quadratic isoparametric element for shell with a three noded beam element for stiffener formulation. Specific numerical problems of earlier investigators are solved to compare their results. Moreover, free vibration problem of stiffened saddle shells with different size and position of the cutouts with respect to the shell centre for different edge constraints are examined to arrive at some conclusions useful to the designers. The results are presented in the form of figures and tables. The results are further analyzed to suggest guidelines to select optimum size and position of the cutout with respect to shell centre considering the different practical constraints.*

Keywords - *stiffened saddle shell, cutout, finite element, free vibration, laminated composites.*

I. INTRODUCTION

Among the different shell forms which are used as roofing units, saddle shells are one of them. Examples of such saddle roofs are: Warszawa Ochota railway station, Church Army Chapel, Blackheath, The Calgary, Saddledome, London Velopark. Quite often, to save weight and also to provide a facility for inspection, cutouts are provided in shell panels. In practice the margin of the cutouts must be stiffened to take account of stress concentration effects. Also, there can be some instruments directly fixed on these panels, and the safety of these instruments can be dependent on the vibration characteristics of the panels. Hence free vibration studies on saddle shell panels with cutouts are of interest to structural engineers.

Free vibration study of doubly curved shells was done by Qatu [1], Liew and Lim [2], Chakravorty et. al [3], Tan [4], and Kant et al [5]. Later, different researchers worked on doubly curved shells from time to time. Qatu et al. [7] reviewed the work done on the vibration aspects of composite shells during 2000 - 2009 and observed that most of the researchers dealt with closed cylindrical shells. Other shell geometries have also been investigated. But, saddle shells on rectangular planform with cutout (stiffened along the margin) are far from complete in the existing literature. Accordingly, the present endeavor focuses on the free vibration behavior of composite saddle shell with cutout (stiffened along the margin) with concentric and eccentric cutouts, and considers the shells to have various boundary conditions.

II. MATHEMATICAL FORMULATION

A laminated composite saddle shell of uniform thickness h (Fig.1) and radius of curvature R_x and R_y is considered. Keeping the total thickness the same, the thickness may consist of any number of thin lamina each of which may be arbitrarily oriented at an angle θ with reference to the X-axis of the co-ordinate system. An eight-noded curved quadratic isoparametric finite element is used. The five degrees of freedom taken into consideration at each node include two in-plane and one transverse displacement and two rotations about the X and Y axes. The detailed finite element formulation for doubly curved shells with cutout stiffened along the margin of the cutout is reported elsewhere [8]. The code developed can take the position and size of cutout as input.

III. VALIDATION STUDY

The present finite element approach is capable of modelling free vibration problem of composite stiffened saddle shells with cutout which is provided by solution of benchmark problems. The validation of